Plan and working progress on cold cBPM for the Main Linac at ILC

Laura Karina Pedraza, Nuria Fuster, Daniel Esperante, Benito Gimeno

Cold BPM R&D Meeting, 08/03/2024

laura.pedraza@ific.uv.es

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I. Project definition and objectives

Development of a **re-entrant cBPM for the ILC Main Linac**

Measurement requirements:

- Spatial resolution < 1 μm
- Temporal resolution < 369 ns
- Dynamic range: 0-35 nm (offset) and 0.1-3.2 nC (bunch charge)

Mechanical requirements:

- Mechanical fit of the BPM and the SC quadrupole magnet
- Cryogenic and UV conditions have to be met

The designed BPM will initially be tested at ATF (Accelerator Test Facility) and at STF (Superconducting RF Test Facility) at KEK where:

- Temporal resolution has to be matched in order to perform bunch to bunch measurements at STF specially

Beam parameters	ATF2	STF	ILC
Beam energy (GeV)	1.3	0.5	250
Bunch charge (nC)	1.6	0.6	3.2
Bunch spacing (ns)	150 or 307	6.15	369
Bunch length (mm)	7	3	0.3

cBPM type	Resonance freq (GHz)	Quality factor Q_L	Decay time τ (ns)
Saclay	1.719	51	9.44
Hayano	2.05	217	33.7

H. Hayano, Development of L-Band Cavity BPM for STF, KEK
C. Simon, N. Rouvière, N. Baboi, Performance of a reentrant cavity beam position monitor, DSM, CNRS, DESY

I. Project definition and objectives

- **Modify the cBPM design to decrease the decay time τ**

❖ Modifications of the Claire Simone design to improve the temporal resolution τ (< 6 ns) → perform bunch to bunch measurements at STF

❖ Evaluate possibility of extracting both monopole and dipole signal from the same output

❖ Mechanical attachment and alignment between the BPM and the SC quadrupole magnet

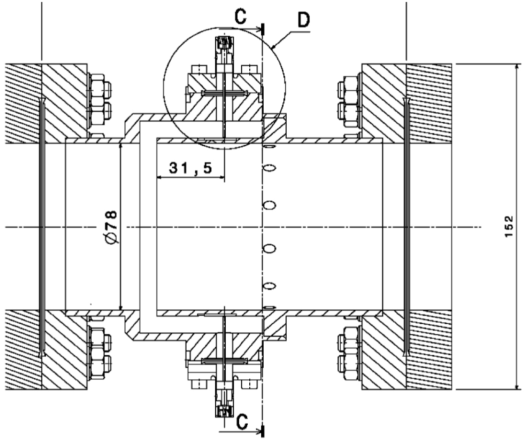
- **Buy a the cBPM from Claire Simone (Saclay)**

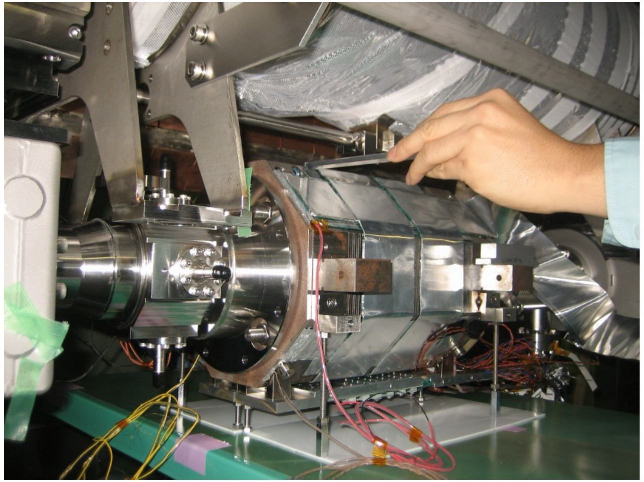
❖ Understand the cBPM behavior

❖ Develop electronics suited for this model

❖ Test the cavity and the electronics without beam at the RF laboratory: preparation of the set-up

❖ Test the cavity and the electronics with beam at ATF





C. Simon, N. Rouvière, N. Baboi, Performance of a reentrant cavity beam position monitor, DSM, CNRS, DESY

II. Working progress A) Simulation of the Saclay model

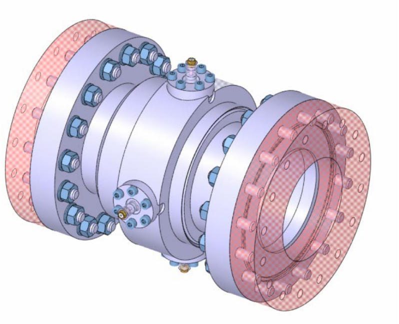


Fig. 8: Design of the new cavity BPM

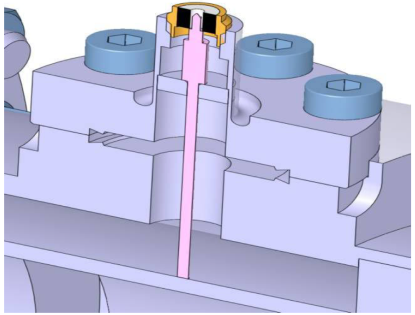
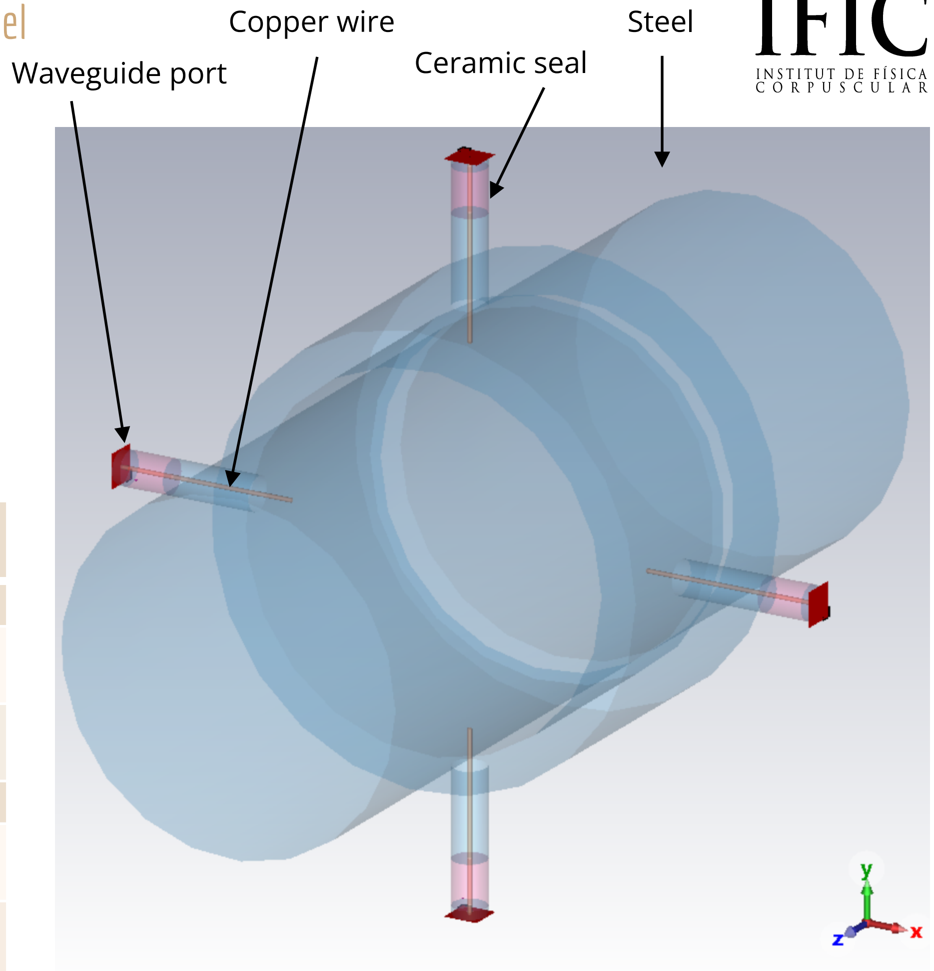


Fig. 9: Design of the new feedthrough

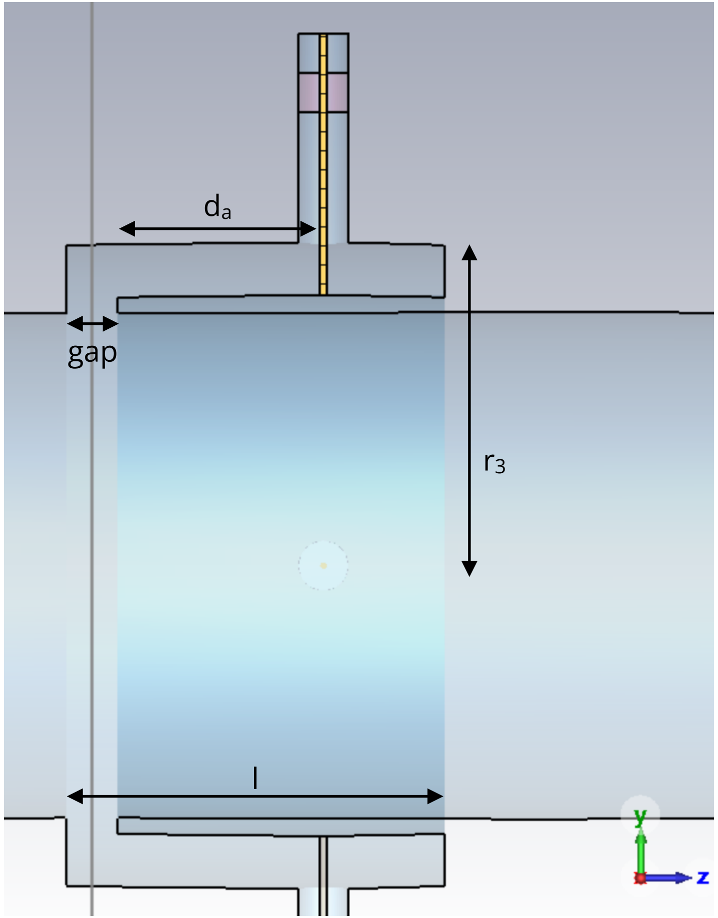
Mode	Frequency ω_{mnp} (GHz)	Loaded Q	Decay time (ns)	R/Q at 5 mm (Ω)
Bibliography				
Mode 1 TM_{010}	1.25	24	6.11	13
Mode 2 TM_{110}	1.72	51.4	9.51	0.25
CST Simulations				
Mode 1 TM_{010}	1.272	15.7	3.97	24.5
Mode 2 TM_{110}	1.728	57.9	11.07	0.46

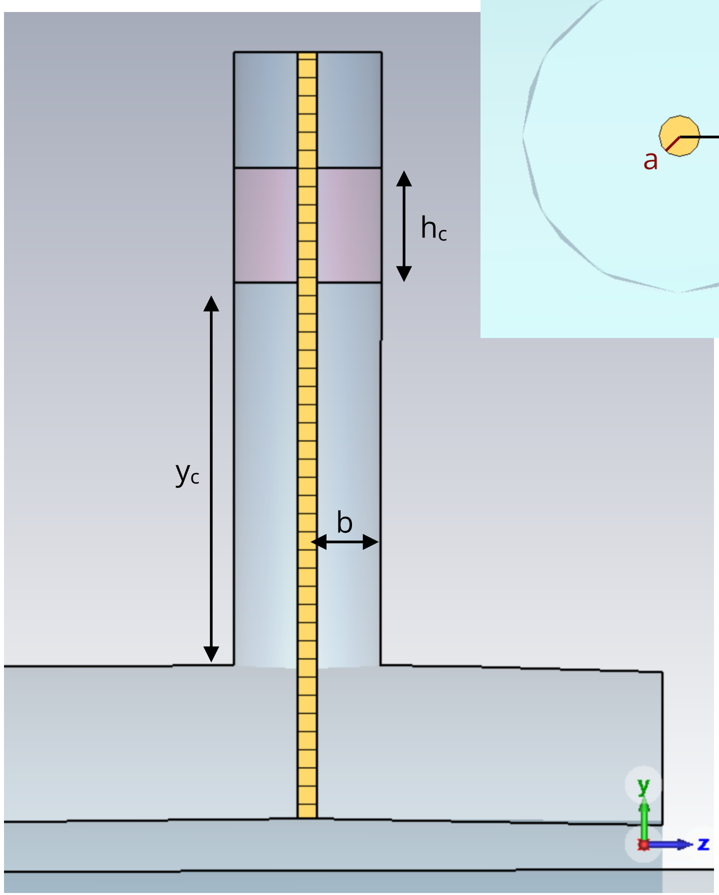


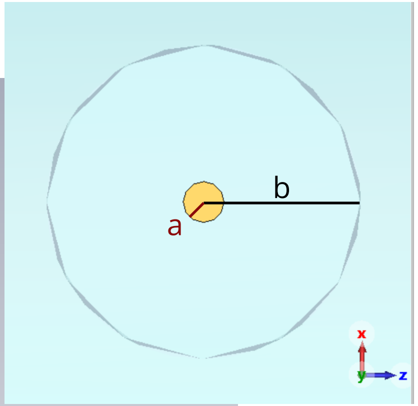
C. Simon, *WP11 (Beam diagnosis) The re-entrant BPM*, CEA, Saclay, France

II. Working progress

A) Simulation of the Saclay model



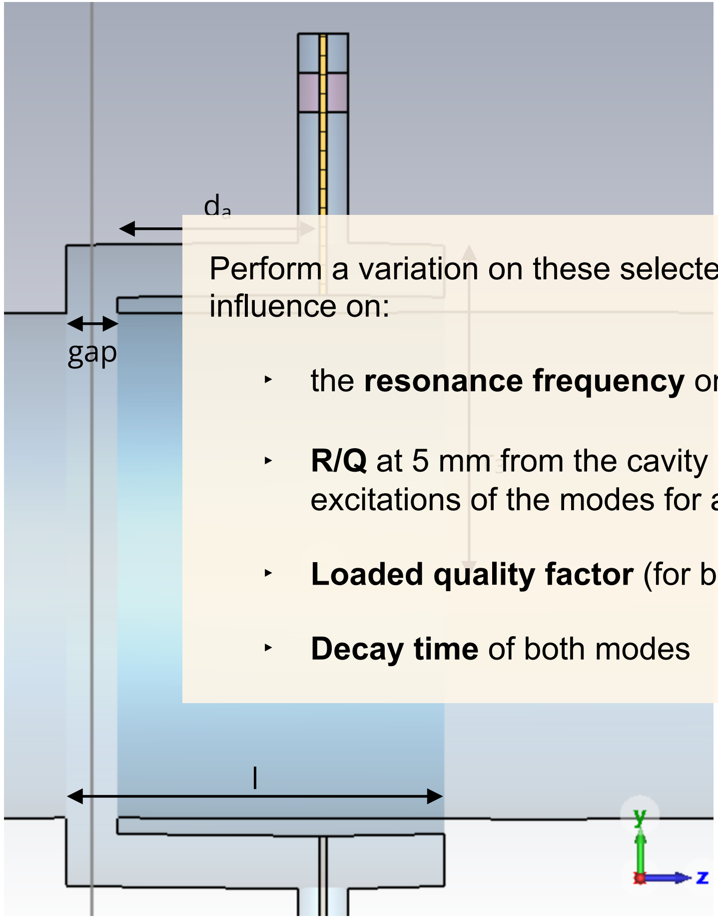


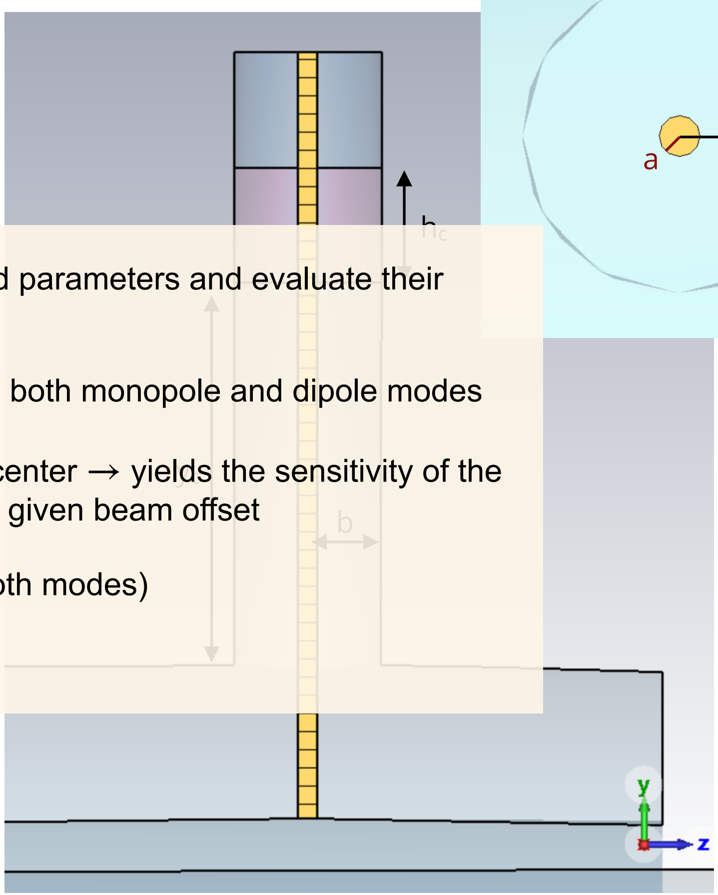


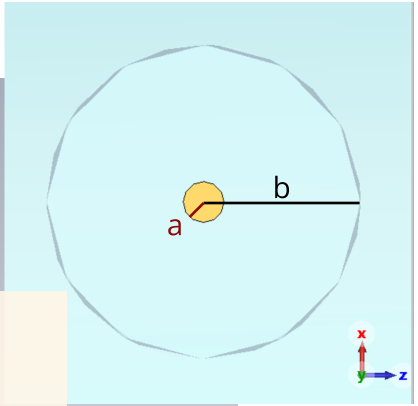
Parameter	Value (mm)
r_3	49.5
gap	8
l	50
d_a	31.5
a	0.5
b	3.85
y_c	20
h_c	10

II. Working progress

B) Parametric studies on CST







Perform a variation on these selected parameters and evaluate their influence on:

- the **resonance frequency** on both monopole and dipole modes
- **R/Q** at 5 mm from the cavity center → yields the sensitivity of the excitations of the modes for a given beam offset
- **Loaded quality factor** (for both modes)
- **Decay time** of both modes

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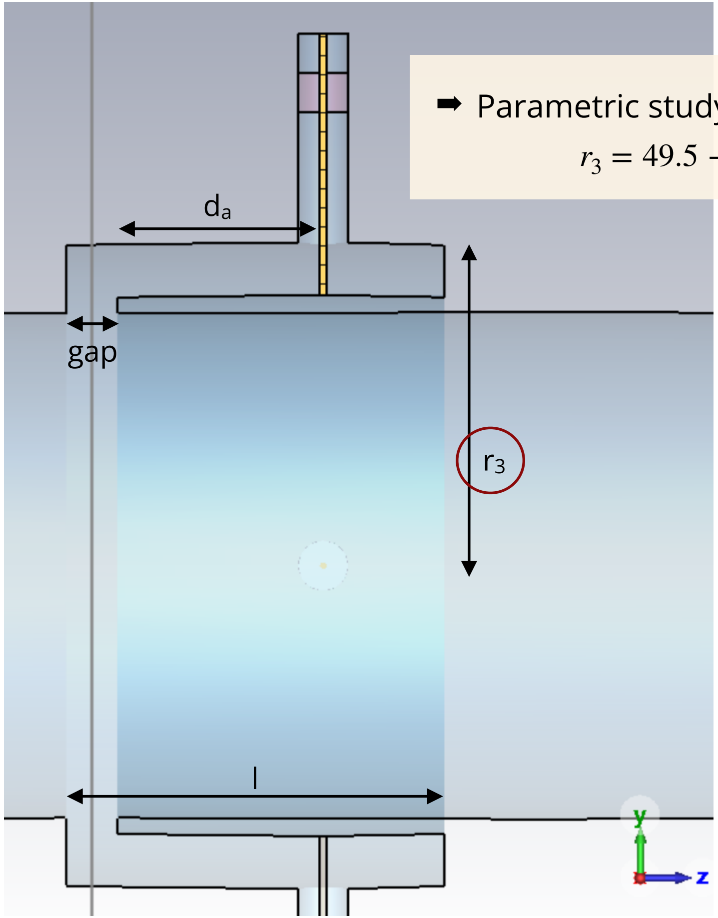
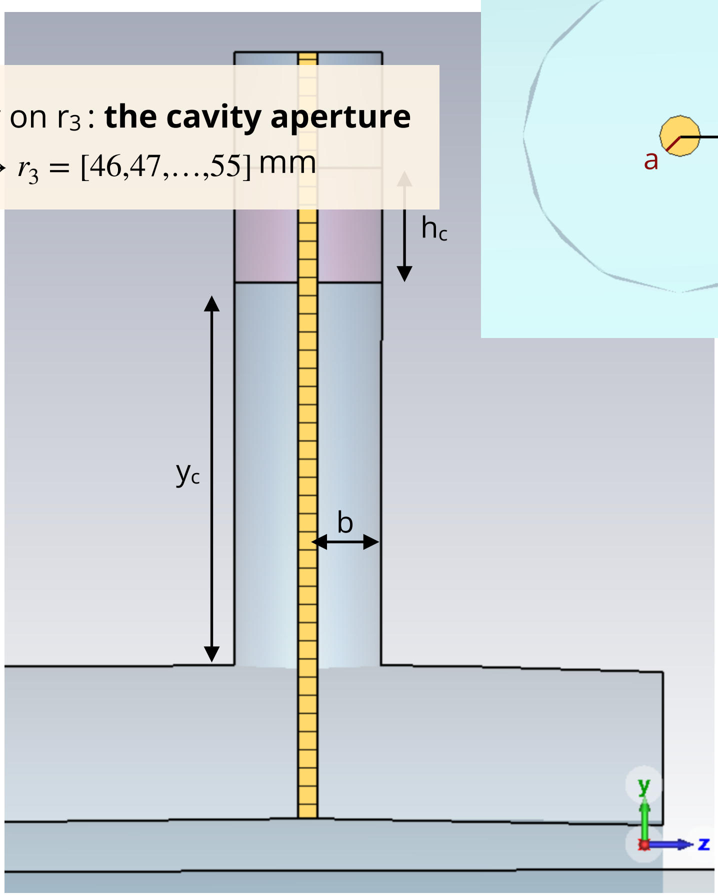
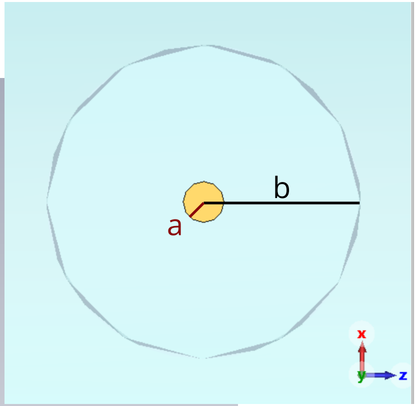
B) Parametric studies on CST

➡ Parametric study on r_3 : **the cavity aperture**

$$r_3 = 49.5 \rightarrow r_3 = [46,47,\ldots,55]\ \text{mm}$$







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II. Working progress B) Parametric studies on CST

➡ Parametric study on r_3 : **the cavity aperture**

$r_3 = 49.5 \rightarrow r_3 = [46,47,\ldots,55]$ mm

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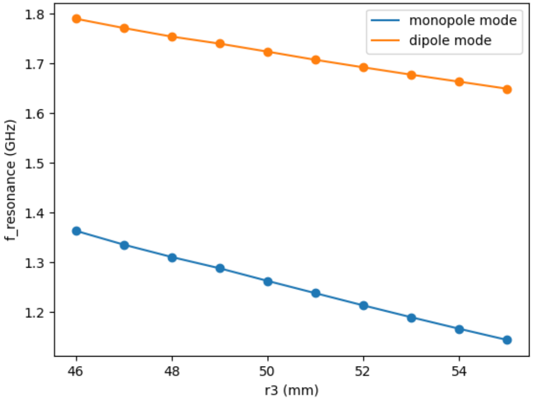
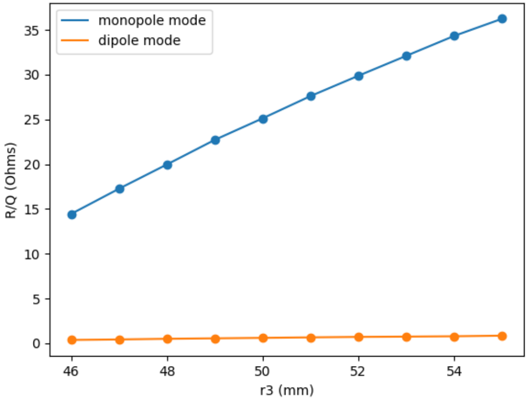
- Resonance frequency



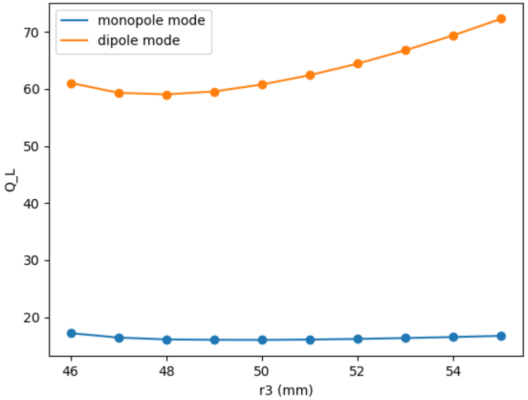
The greater the cavity aperture, the lower the resonance frequency

- R/Q at $y = 5$ mm



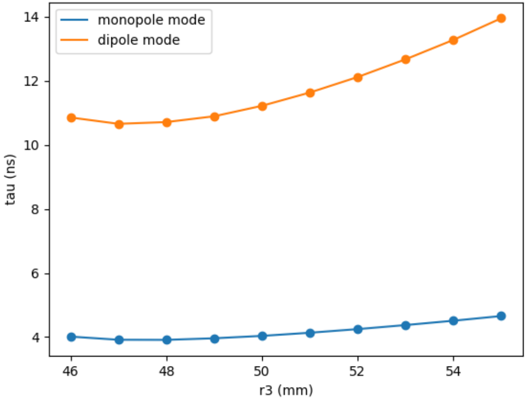
R/Q increases for the monopole -> the amplitude for the monopole increases

- Loaded quality factor



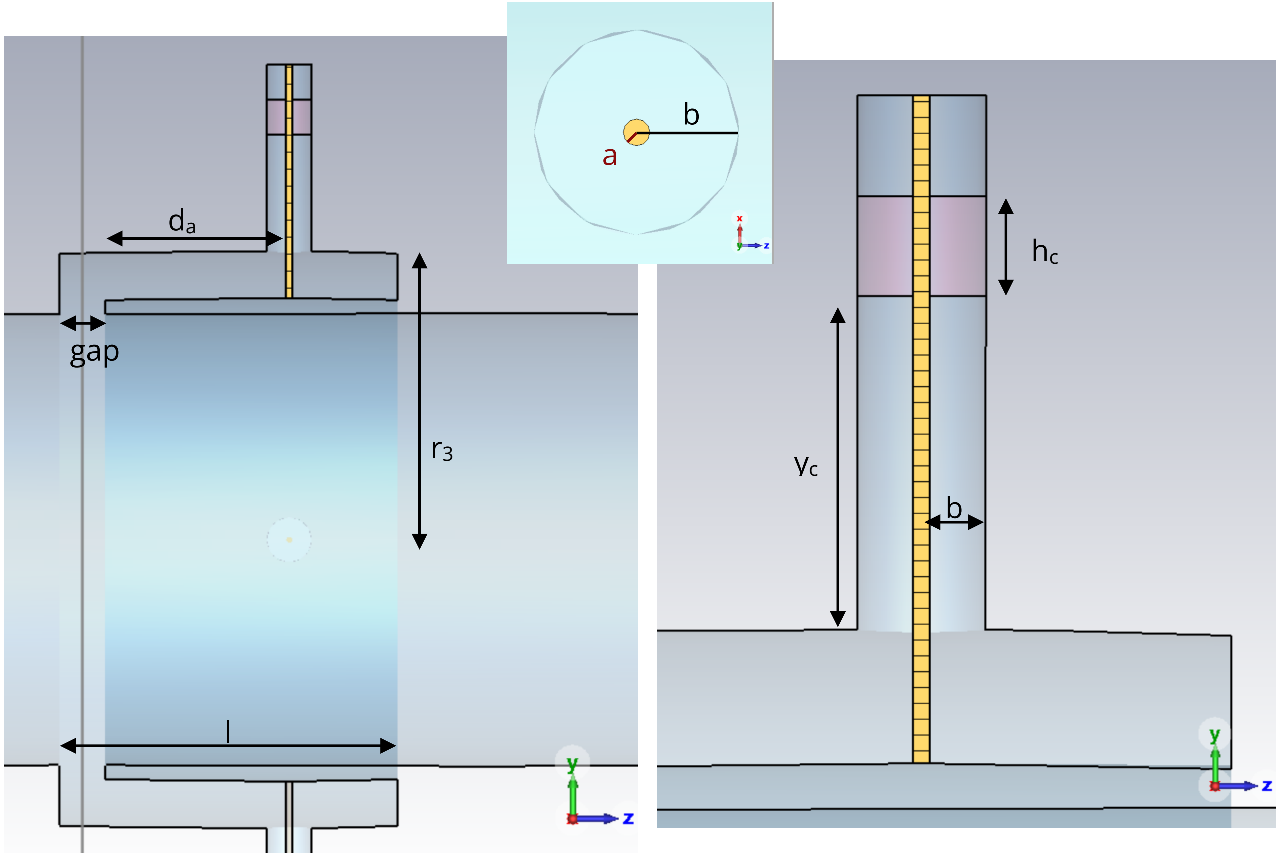
The loaded Q factor of the dipole mode increases (the decay time is longer)

- Decay time



II. Working progress

B) Parametric studies on CST



Preliminary conclusions:

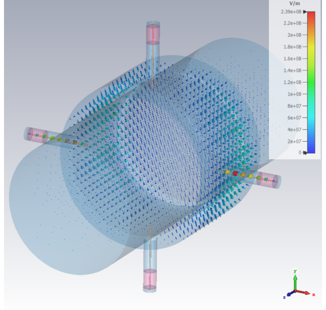
Higher influence on **$Q_{L\,(dipole)}$** (and **τ**):

- ↘ when l ↗ (cavity length)
- ↗ when d_a ↗ (antenna distance)
- ↗ when h_c ↗ (thickness of seal)
- ↘ when a ↗ (radius of inner conductor) (but limited)

Higher influence on **R/Q (dipole)** (sensitivity):

- ↗ when r_3 ↗ (cavity aperture)
- ↘ when l ↗ (cavity length)

➡ Parameters usually affect al variables at the same time. Need of careful selection.



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BI-RME 3D = Boundary Integral - Resonant Mode Expansion

Hybrid method that uses CST field results for a closed resonant cavity and allows to evaluate the RF power extracted at the output ports from the cavity when excited by a beam

➡ For a given operation frequency, the numerical method yields:

- power consumed by the cavity P_c and power delivered to the waveguides (ports) P_w
- output RF signal's amplitude and phase
- external and loaded quality factors

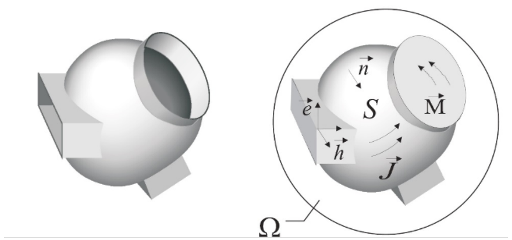
Method:

- The EM fields within a cavity can be expressed as a superposition of the full set of solenoidal and irrotational modes.
- The expressions of the electric and magnetic fields existing in the cavity excited by the time-harmonic electric $\vec{J}$ and magnetic $\vec{M}$ current densities are:

$$\vec{E}(\vec{r}) = \frac{\eta}{jk}\nabla\int_V g^e(\vec{r},\vec{r}')\,\nabla'\cdot\vec{J}(\vec{r}')\,dV' - jk\eta\int_V \vec{\mathbf{G}}^{\mathrm{A}}(\vec{r},\vec{r}')\cdot\vec{J}(\vec{r}')\,dV' - \\ -\int_S \nabla\times\vec{\mathbf{G}}^{\mathrm{F}}(\vec{r},\vec{r}')\cdot\vec{M}(\vec{r}')\,dS' + \frac{1}{2}\vec{n}\times\vec{M}$$

$$\vec{H}(\vec{r}) = \frac{1}{jk\eta}\nabla_s\int_S g^m(\vec{r},\vec{r}')\,\nabla'\cdot\vec{M}(\vec{r}')\,dS' - \frac{jk}{\eta}\int_S \vec{\mathbf{G}}^{\mathrm{F}}(\vec{r},\vec{r}')\cdot\vec{M}(\vec{r}')\,dS' + \\ +\int_V \nabla\times\vec{\mathbf{G}}^{\mathrm{A}}(\vec{r},\vec{r}')\cdot\vec{J}(\vec{r}')\,dV'$$

for a set of scalars and tensors of Green functions under the Coulomb gauge



B. Gimeno, *Wide-band full-wave electromagnetic modal analysis of the coupling between dark-matter axions and microwave resonators, AITANA Seminar 2024*

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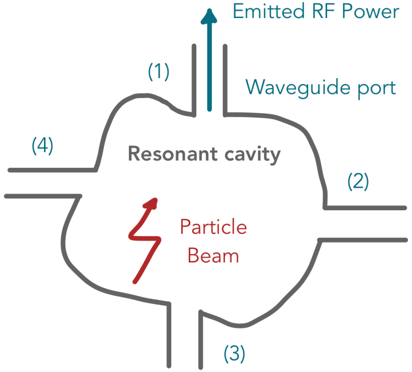
A cavity BPM can be considered as a resonant cavity with 4 waveguide ports as outputs:



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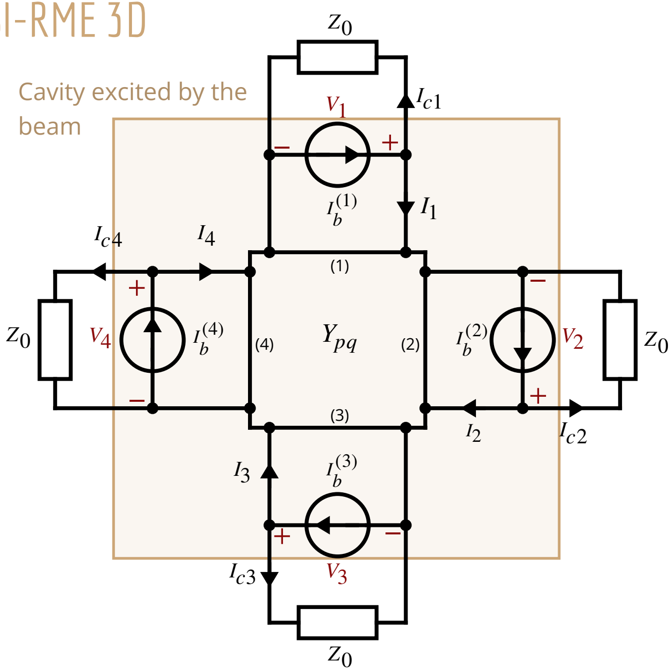


Variable definition:

Z_0 impedance of coaxial output

V_i voltage at port (i)

$I_i = I_b^{(i)} - I_{ci}$ intensity at the cavity

$I_{ci} = V_i / Z_0$ intensity at the coaxial port

$$\begin{pmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{pmatrix} = \begin{pmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{pmatrix} \cdot \begin{pmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{pmatrix}$$

Input admittance of the cavity

$$I_b^{(i)} = \sum_{m=1}^{3} \frac{\kappa_m}{k^2 - \kappa_m^2} \int_{S^{(i)}} \vec{H}_m \cdot \vec{h}_{TEM}^{(i)} dS \int_V \vec{E}_m \cdot \vec{J}_b dV$$

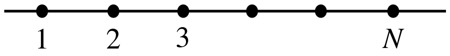
Coupling cavity-port

Coupling beam-cavity

Intensity generated by the beam leading to port (i)

$$\kappa_m \simeq k_m \left(1 - \frac{1}{2Q_m}\right) + j \frac{\kappa_m}{2Q_m}$$ to consider Ohmic losses

$$\vec{J}_b = \sum_{n=1}^{N} q_n \delta(\vec{r} - \vec{r}_n') \vec{v}_n$$ is the beam current density



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III. Future planning

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New cBPM design

Crossed examination of parameters for a detailed optimization

Start developing cBPM design to fit
- measurement requirements: temporal resolution < 6.15 ns
- mechanical requirements: mechanical fit with the SC quadrupole

Examine results with BI-RME 3D

Saclay model

Acquire the cBPM model from C. Simone → summer/fall 2024

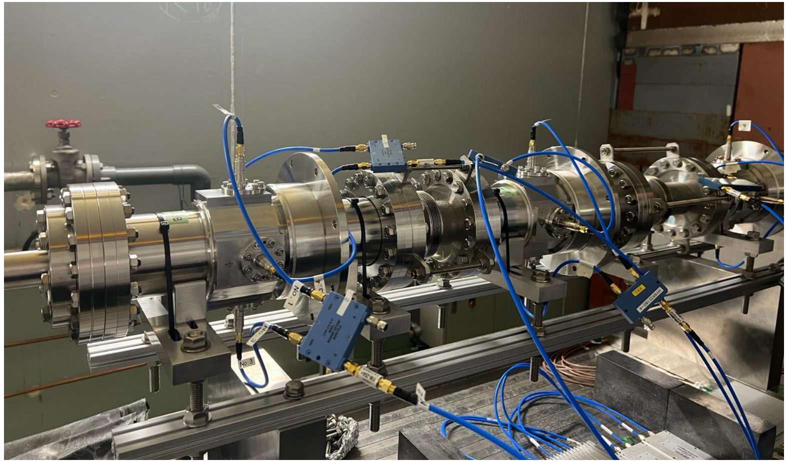
Start developing the electronics readout to test with this model
Possibility of collaboration with the RHUL / ELI + KEK (test their electronics)

Prepare set-up for cBPM at RF laboratory (IFIC)

Measurements at ATF and STF

Possibility to perform measurements at the end of 2024, provided that we receive the cBPM from Saclay and have the read-out system ready

Available space to perform measurements at ATF:
- drift space right before the QM16FF magnet (ATF2)
- end of Linac with Korean group



Thank you for your attention

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